What Drives 20th Century Polar Motion?

Surendra Adhikari
(surendra.adhikari@jpl.nasa.gov)

Lambert Caron | John T. Reager | Eric Larour | Eric R. Ivins
NASA Jet Propulsion Laboratory, California Institute of Technology, USA

Bernhard Steinberger
GFZ German Research Center for Geosciences | University of Oslo, Norway

Kristian K. Kjeldsen
Technical University of Denmark, Denmark

Ben Marzeion
University of Bermen, Germany

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20th century secular polar motion.
(from a compilation of Gross, 2007)

- Speed: 10.5 ± 0.9 cm/year
- Direction: $74.2° \pm 4.7°$ west longitude

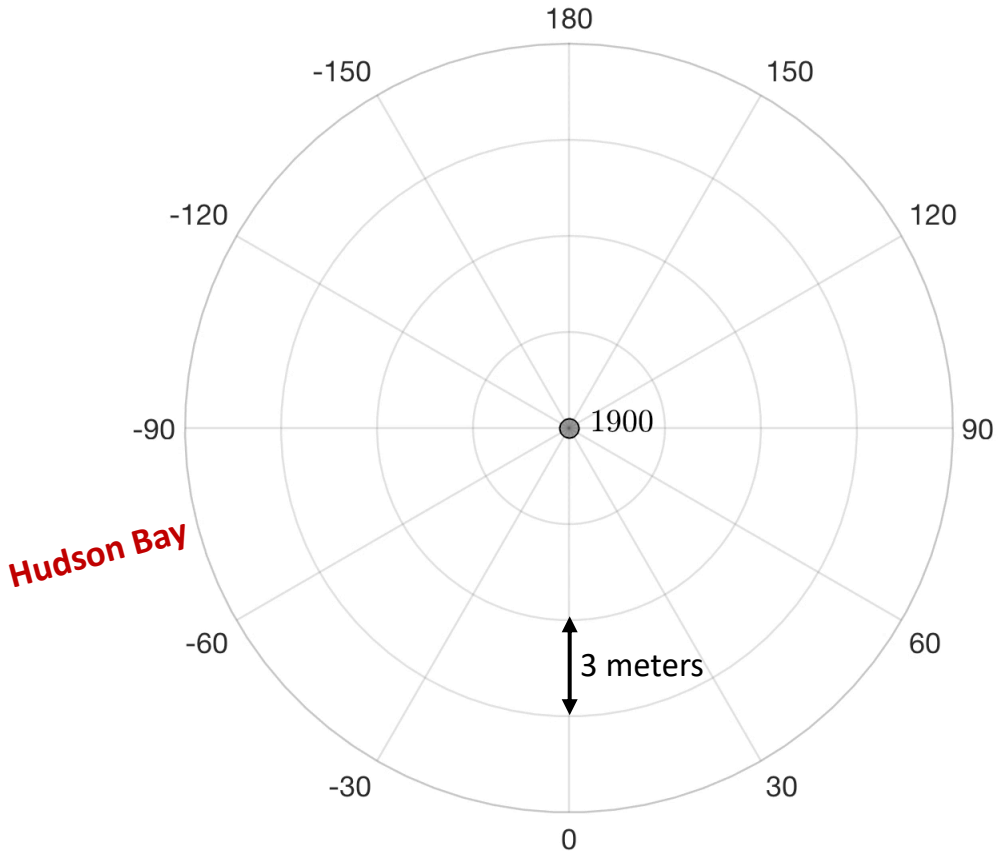
Earth's mass distribution → Inertia tensor, $I(t)$

$$\frac{d}{dt}[\omega(t) \cdot I(t)] + \omega(t) \times [\omega(t) \cdot I(t)] = 0$$

Angular velocity vector, $\omega(t)$ → **Polar motion**

What aspects of mass transport drive secular polar motion? is the question.

Mean annual (north) pole position.



Data courtesy of IERS (https://www.iers.org).
Chandler & higher frequency signals removed.
Time series smoothed with a 6-yr running window.

Glacial isostatic adjustment (GIA).

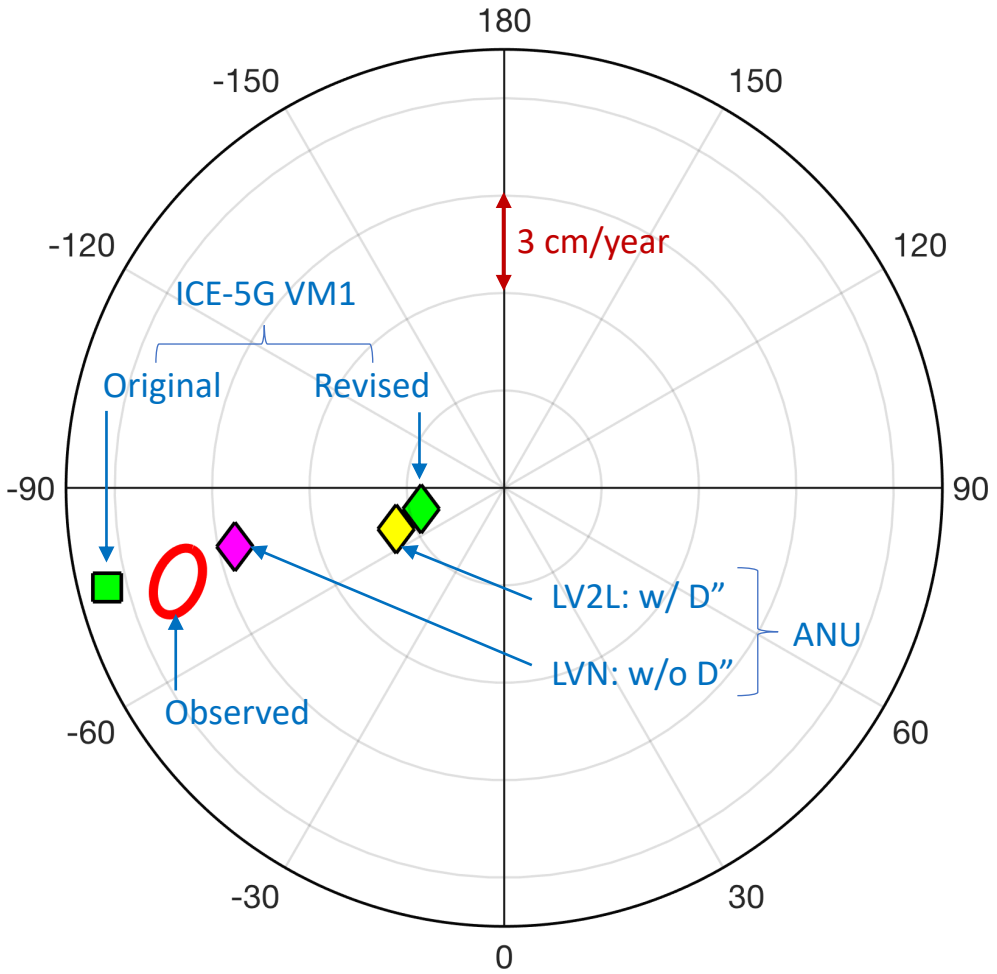
- Original ice-age rotation theory
  (Wu & Peltier, 1976, *GJRAS*)
- Revised theory (w/ excess ellipticity)
  (Mitrovica et al., 2005, *GJI*)
- Inclusion of low-viscosity D" layer
  (Nakada et al., 2015, *GJI*)

Non-GIA excitation sources.

- Mantle convection
  (Steinberger & O'Connell, 1997, *Nature*)
- Earth's surface mass transport
  (Munk, 2002, *PNAS*; Adhikari & Ivins, 2016, *Sci. Adv.*)
- Seismogenic mass transport
  (Chao & Gross, 1987, *GJRAS*; Cambiotti et al., 2016, *GJI*)
- Core-mantle coupling etc.

Goal: To unifying partial sources of excitation!

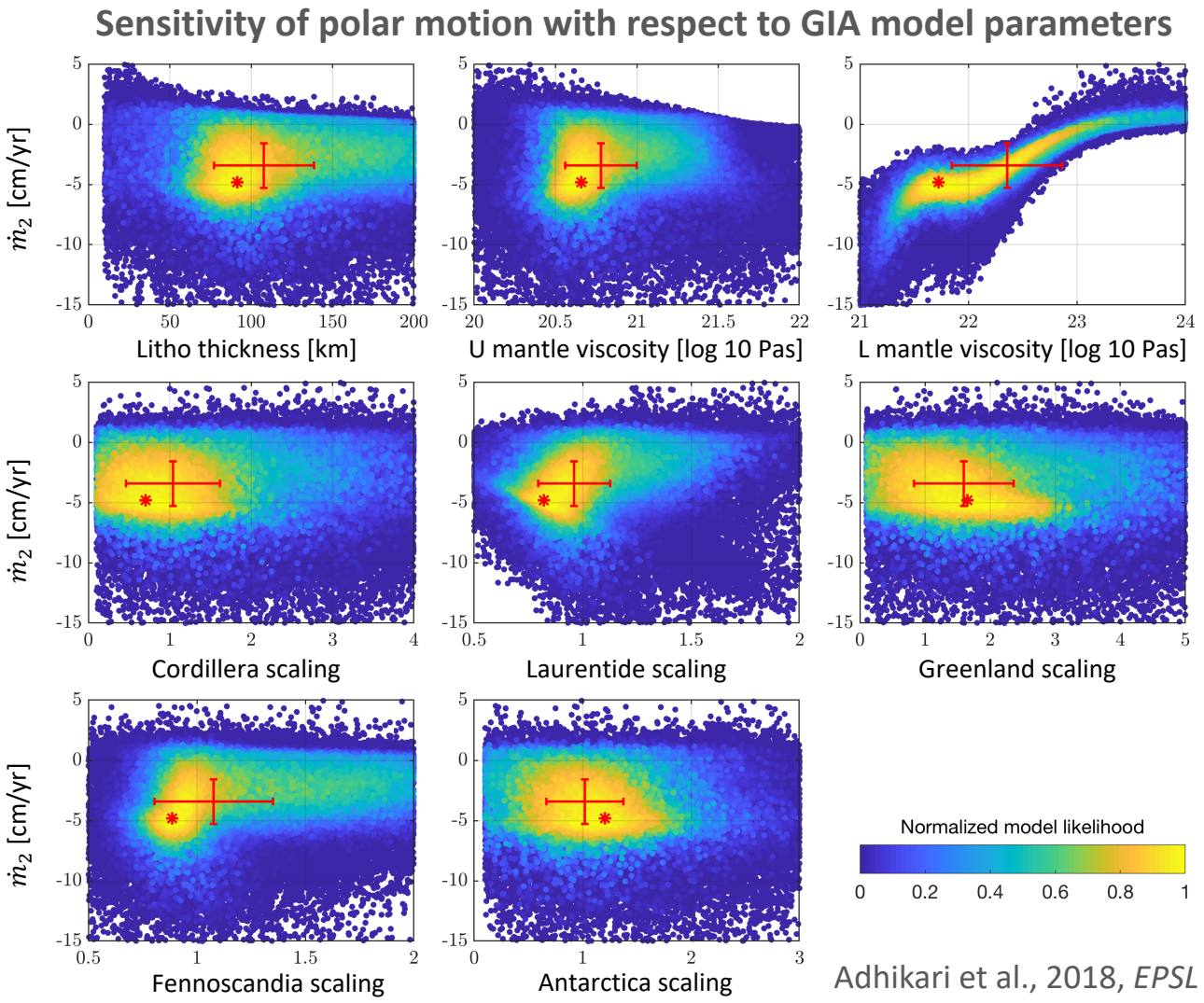
Non-uniqueness in GIA-driven polar motion.



ICE-5G solutions are adapted from Mitrovica et al., 2015, *Sci Adv.*
ANU solutions are from Nakada et al., 2015, *GJI*.

Bayesian GIA models.
(Caron et al., 2018, *GRL*)

- 1-D, 3 mantle layers
- 128,000 model realizations
- 8 GIA parameters explored freely
  - 3 solid-Earth parameters
  - 5 deglaciation parameters (based on ANU & ICE-6G)
- 11,451 RSL data
- 459 GPS stations

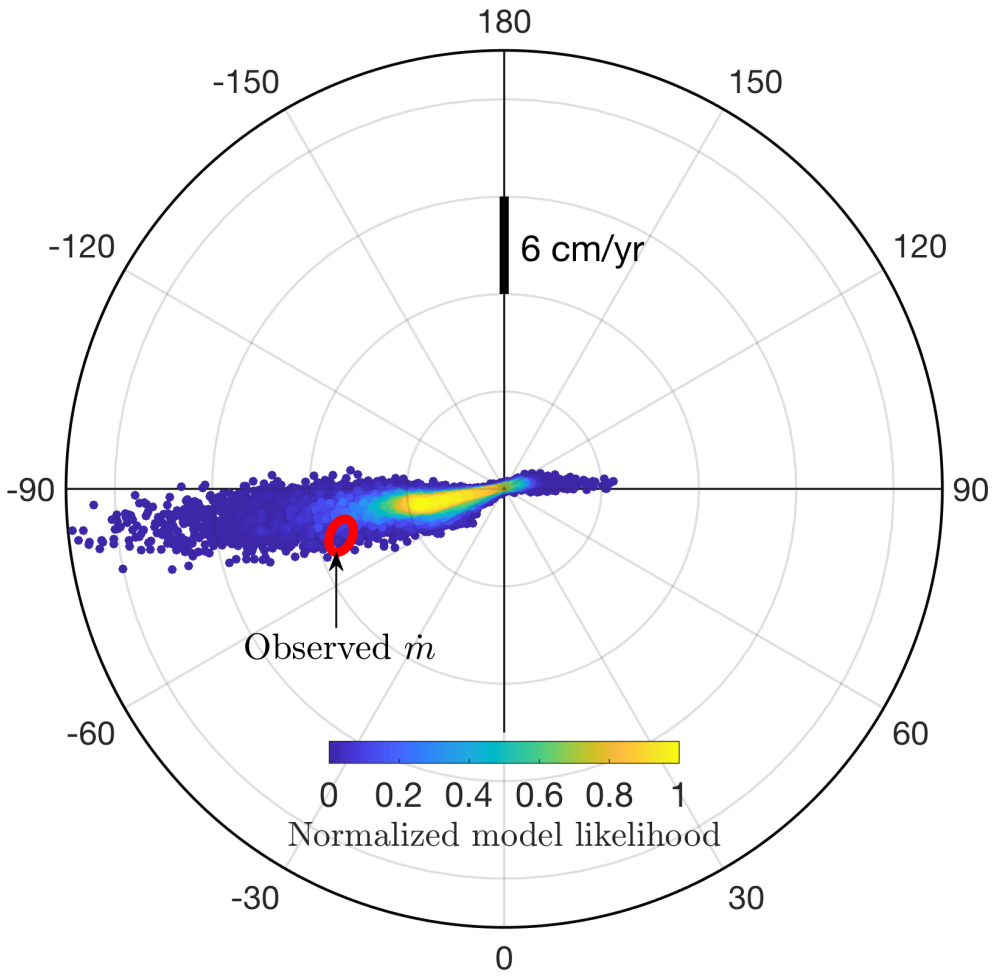


Adhikari et al., 2018, *EPSL*

Polar motion due to GIA.
(Adhikari et al., 2018, *EPSL*)

- Speed: 3.5 ± 1.9 cm/year
  $33 \pm 18\%$ of the observed amplitude.

- Direction: $79.4° \pm 2.9°$ west longitude
  within $5.2° \pm 5.5°$ of the observed direction.

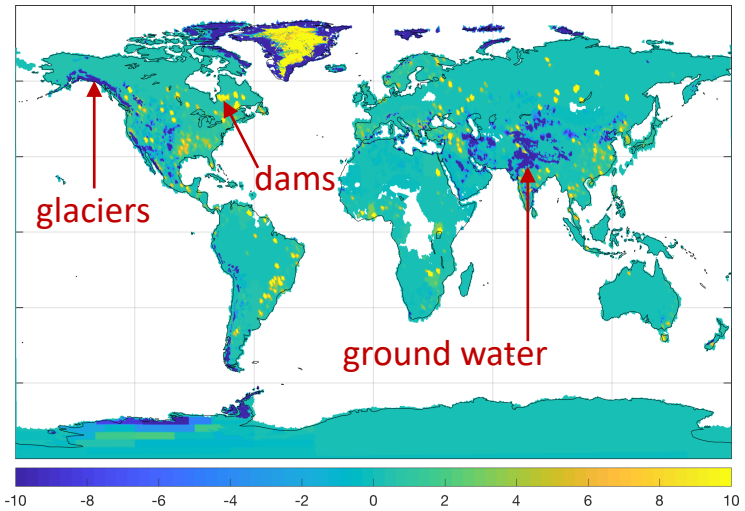


Earth's surface mass transport: 1900-2000

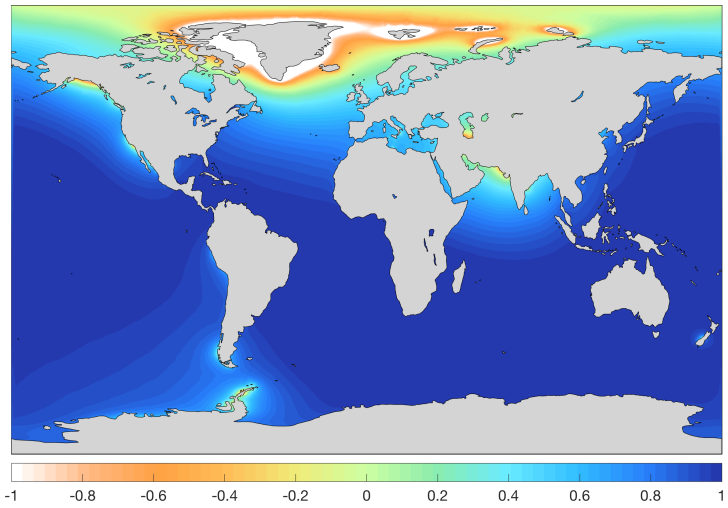
	GMSL rate [mm yr^{-1}]	References/notes
Global glaciers	0.60 ± 0.04	Marzeion et al., 2015, *Cryosphere*
Greenland	0.21 ± 0.09	Kjeldsen et al., 2015, *Nature*
Antarctica	0.05 ± 0.06	Smith et al., 2017, *Nature* Christ et al., 2014, *GSA Bulletin* Cook et al., 2005, *Science* Miles et al., 2016, *Sci. Adv.* Monagham et al., 2016, *Science* Ivins et al., 2009, *JGR*
Groundwater	0.17 ± 0.07	Wada et al., 2012, *GRL*
Dams/reservoirs	-0.29	GRanD dataset: www.gwsp.org Chao et al., 2008, *Science*
Steric	$[0.26, 1.26]$	Note: To satisfy the total GMSL
Total	$[1.0, 2.0]$	

Adhikari et al., 2018, *EPSL*

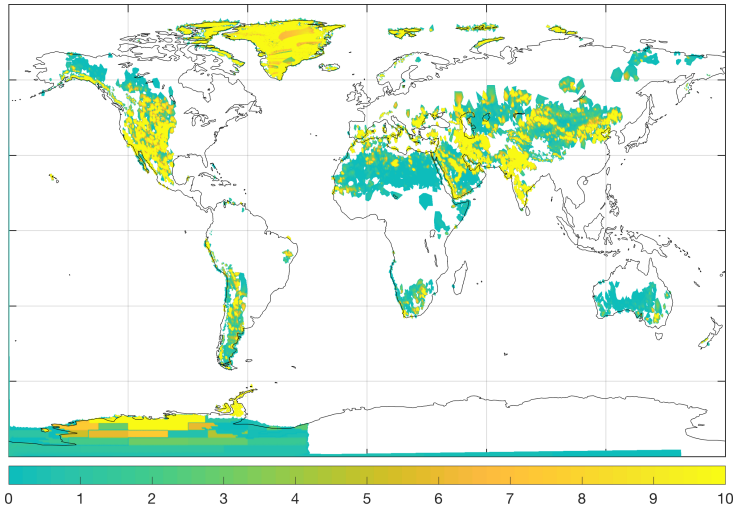
Land water height change [mm/yr]



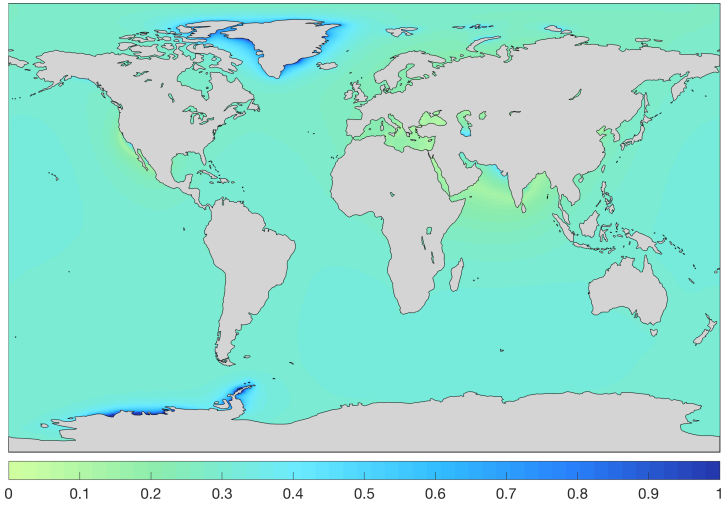
Non-steric relative sea-level [mm/yr]



1-σ uncertainties [mm/yr]



1-σ uncertainties [mm/yr]



Polar motion due to Surface Mass Transport.

1900-2000

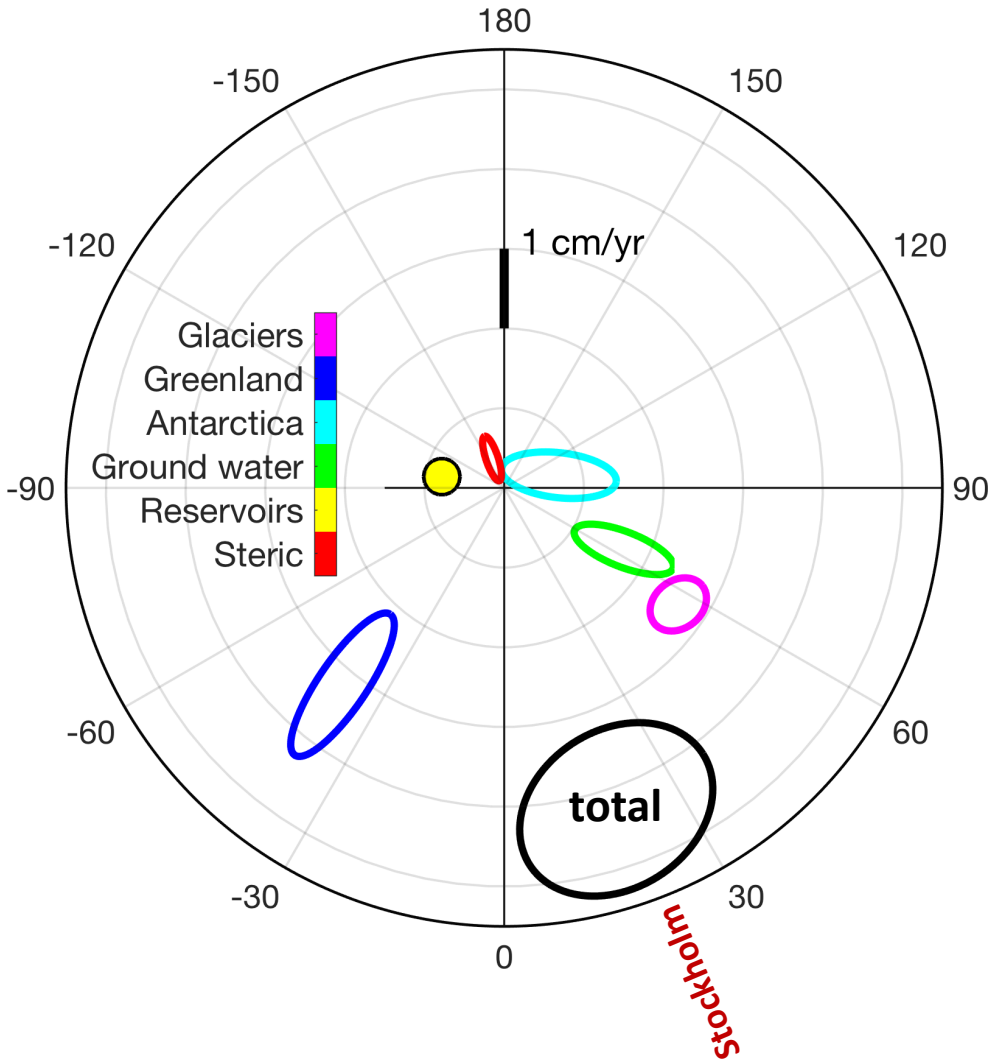
(Adhikari et al., 2018, *EPSL*)

- Speed: 4.3 ± 1.0 cm/year
- Direction: $19.2° \pm 16.1°$ east longitude

2003-2016 (GRACE period)

(Chen et al., 2013, *GRL*; Adhikari & Ivins, 2016, *Sci. Adv.*)

- Speed: ~ 14.2 cm/year
- Direction: $\sim 27.7°$ east longitude



Mantle Convection.

(Steinberger et al., 2017, *GRL*; Adhikari et al., 2018, *EPSL*)

[1] Slab subduction driven forward models

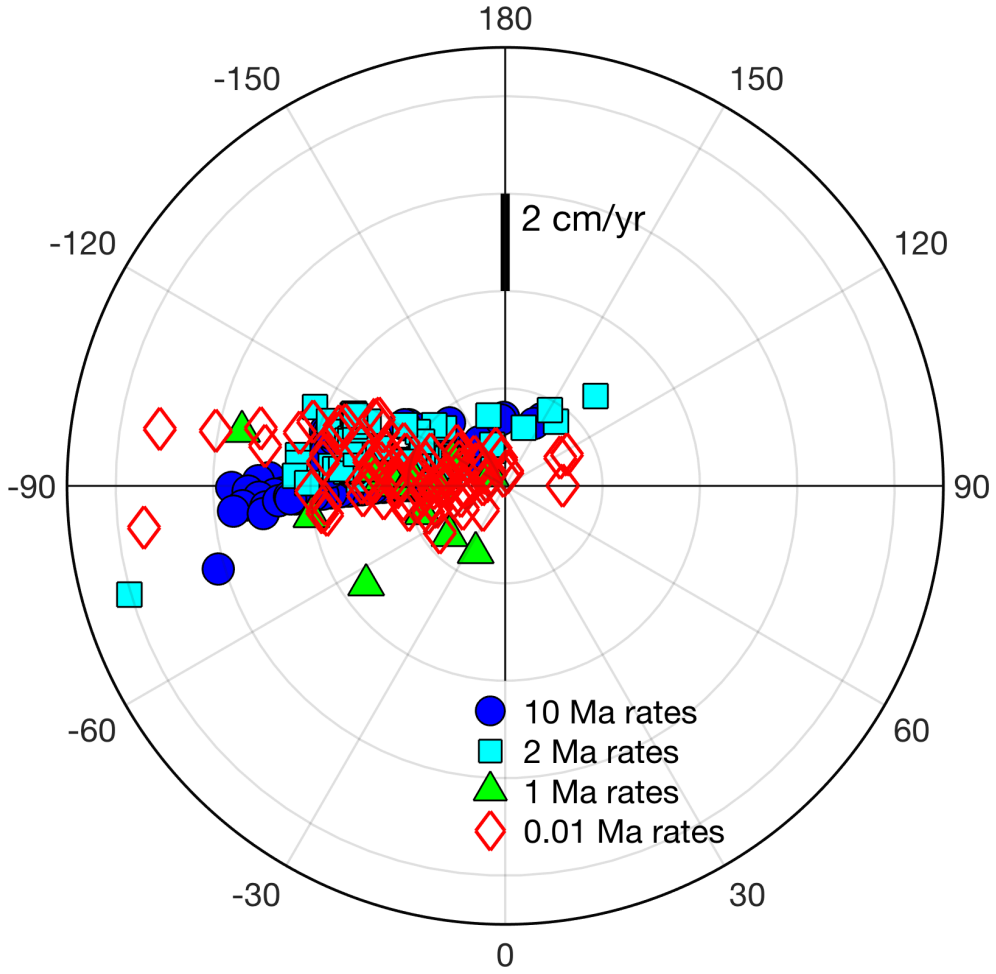
(Spada et al., 1992, *Nature*; Steinberger et al., 2017, *GRL*)

- Trained by past tectonic plate motions
- Aimed at predicting seismic tomography

[2] Backward advection approach

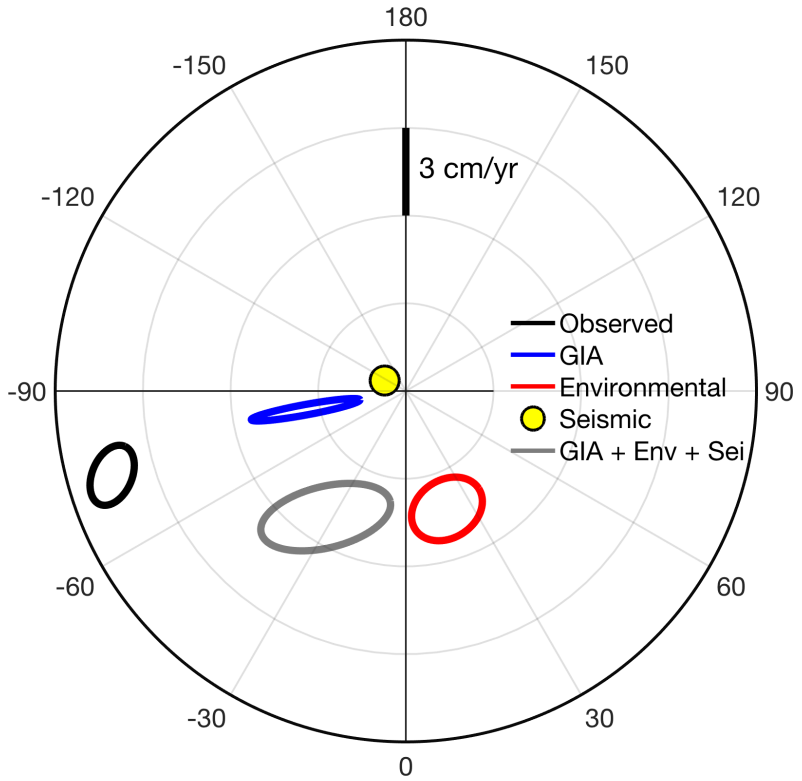
(Ricard et al., 1993, *GJI*; Steinberger et al., 1997, *Nature*)

- Informed by present-day seismic tomography
- Aimed at reconstructing past plate motions



Method [1] solutions retrieved at 2 & 10 Ma (94 models each).
Method [2] solutions retrieved at 1 (13 models) & 0.01 Ma (82).

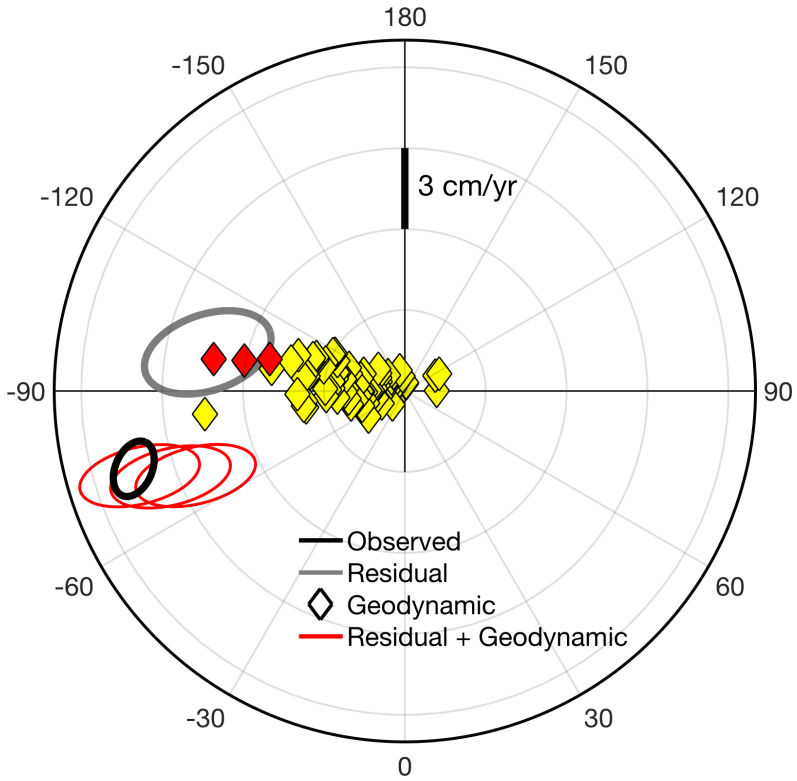
20th century polar motion: Budget analysis
WITHOUT mantle convection



[1] GIA is treated with Bayesian Statistics (128k models, 8 parameters, 12k RSL/GPS data).

[2] All of the Seismogenic (Cambiotti et al., 2010, *GJI*) and Environmental sources are assessed w/ their 1-σ errors.

20th century polar motion: Budget analysis
WITH mantle convection



[3] 293 Geodynamic models do contain a finite set of predictions that help reconcile the observed motion.

[4] Proposal: Pursue polar motion based joint Geodynamic & GIA model inversions for lower mantle viscosity!

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@AlpineGlaciers

Surendra.Adhikari@jpl.nasa.gov